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TECHNICAL REPORT 4287

YEAR-ROUND VISIBILITY LIMITS FOR SCHEDULING YAW SONDE FIRINGS

G. L. GERHARD

MARCH 1972

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Picatinny Arsenal, Dover, New Jersey 07801	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE

YEAR-ROUND VISIBILITY LIMITS FOR SCHEDULING YAW SONDE FIRINGS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

S. L. Gerhard

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
	46	17

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	Technical Report 4287
c. AMCMS Code 4810.16.2222.6	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

To study the rotational motion of projectiles in free flight, yaw sonde devices are mounted in them to record the motion. Since these devices use the sun's rays to obtain a record, it is necessary to fire test rounds only at times when the sun is in a favorable position. This report describes a method for determining these times for any given firing site. Year charts for three sites (NWC, China Lake, California; Yuma Proving Ground, Yuma, Arizona; and NASA, Wallops Island, Virginia) are shown. From such charts, the most favorable firing times may be chosen for each day in any given year. Range azimuth is the most important factor in determining whether the yaw sonde will see the sun. The nearly north-south range at China Lake, California, is most favorable, allowing firings before 0830 hours and after 1430 hours all year long. The east-west range at Yuma Proving Ground, Arizona, is least favorable allowing firings only in three winter months between 0900 and 1400 hours. Wallops Island, Virginia allows firings after 1300 hours from September to April. Out of the 0°, 30°, 45°, and 60° quadrant elevations considered, the 60° quadrant elevation offers the most restricted opportunities for firing at every site.

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AMCMS Code 4810.16.2222.6

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ABSTRACT

To study the rotational motion of projectiles in free flight, yaw sonde devices are mounted in them to record the motion. Since these devices use the sun's rays to obtain a record, it is necessary to fire test rounds only at times when the sun is in a favorable position. This report describes a method for determining these times for any given firing site. Year charts for three sites (NWC, China Lake, California, Yuma Proving Ground, Yuma, Arizona; and NASA, Wallops Island, Virginia) are shown. From such charts, the most favorable firing times may be chosen for each day in any given year. Range azimuth is the most important factor in determining whether the yaw sonde will see the sun. The nearly north-south range at China Lake, California, is most favorable, allowing firings before 0830 hours and after 1430 hours all year long. The east-west range at Yuma Pr ing Ground, Arizona, is least favorable allowing firings only in three winter months between 0900 and 1400 hours. Wallops Island, Virginia allows firings after 1300 hours from September to April. Out of the 0°, 30°, 45°, and 60° quadrant elevations considered, the 60° quadrant elevation offers the most restricted opportunities for firing at every site.

NOTATION

A	Sun's azimuth
E	Sun's elevation
D	Sun's declination
L	Latitude of firing site
R	Range azimuth
Q	Quadrant elevation
S	Unit sun vector
V	Unit velocity vector
ψ	Angle between S and V
LHA, H	Hour angle of sun
CVT	Civil standard time
LMT	Local mean time
DLG	Longitude correction on LMT
MP	Meridian passage at LMT
v	Initial (muzzle) velocity
x	Horizontal coordinate
y	Vertical coordinate
g	Acceleration due to gravity
r	Horizontal range
h	Height
y'	dy/dx = slope

Subscripts

1, 2, 3 On any vector denote its x, y, z components

X, Y, Z Coordinate axes in Figure 1

INTRODUCTION

One of the devices used to study the angular motion of projectiles in free flight is the yaw sonde (Ref 1). Since these devices use the sun's rays to obtain a record, test projectiles should be fired only when the sun shines from a particular direction on the side of the projectile while in flight. To schedule yaw sonde firings, it is therefore necessary to know in advance when the sun will be in a favorable position. The work described in this report was done to fulfill this need at three firing sites. A general method was devised for predicting the sun's visibility at any given range (azimuth and latitude) on any day of any year.

The computational techniques employed here are more comprehensive than those used previously. La Combe's technique (Ref 2) was restricted to a single day in a certain year, based on Nautical Almanac data for the date in question. The basis for our new technique was furnished by Doan and Sandford (Ref 3) who showed that for many practical applications, where an error of 1° in the sun's position is acceptable, the year-to-year changes in the sun's position on a given day are negligible. Doan and Sandford provide two sets of graphs the combination of which forms the key to the solution of our problem.

Two independent lines of computation are combined to obtain the desired results. The first line uses the yaw sonde trajectory characteristics to determine where the sun must be for yaw sonde recordings. The second line uses the chart devised on the basis of Reference 3 to tell when the sun will be in these desired positions.

THEORY AND PROCEDURE

Limit Calculations

The purpose in this first line of computation is to locate the sun when it is on the edge of the field of view of the yaw sonde at certain stages in the flight of a projectile. The position of the sun is defined by a unit vector S which is defined by two angles, A and E, representing azimuth and elevation, respectively, as Figure 1 shows. In the same figure, it can be seen that the components of this unit sun vector are

$$S_1 = \cos E \cos A$$

$$S_2 = \sin E \qquad (1)$$

$$S_3 = \cos E \sin A$$

The sun is assumed to be stationary relative to the earth during the entire flight of the projectile. However, the field of view of the yaw sonde changes as the projectile follows the tangent to the trajectory; hence, the sun may be visible at one stage of flight and not at another.

The orientation of the projectile is given by unit vector V, whose components are

$$V_1 = \cos Q \cos R$$

$$V_2 = \sin Q \qquad (2)$$

$$V_3 = \cos Q \sin R$$

where R is the range azimuth and Q is the quadrant elevation. This unit vector is called the velocity, but it really is the vector along the projectile axis, which is here assumed to be tangent to the trajectory, i.e., the projectile flies without yaw. This is a slight limitation that will be discussed later. The sun's visibility was calculated for three segments of the trajectory, by setting Q equal to QE, zero, and -QE, representing launch, peak, and impact, respectively. This assumes a parabolic trajectory, where the descending portion is a mirror image of the ascending portion. This assumption is valid in this project, because the difference between actual and vacuum trajectories is within the range of error in locating the visibility limits.

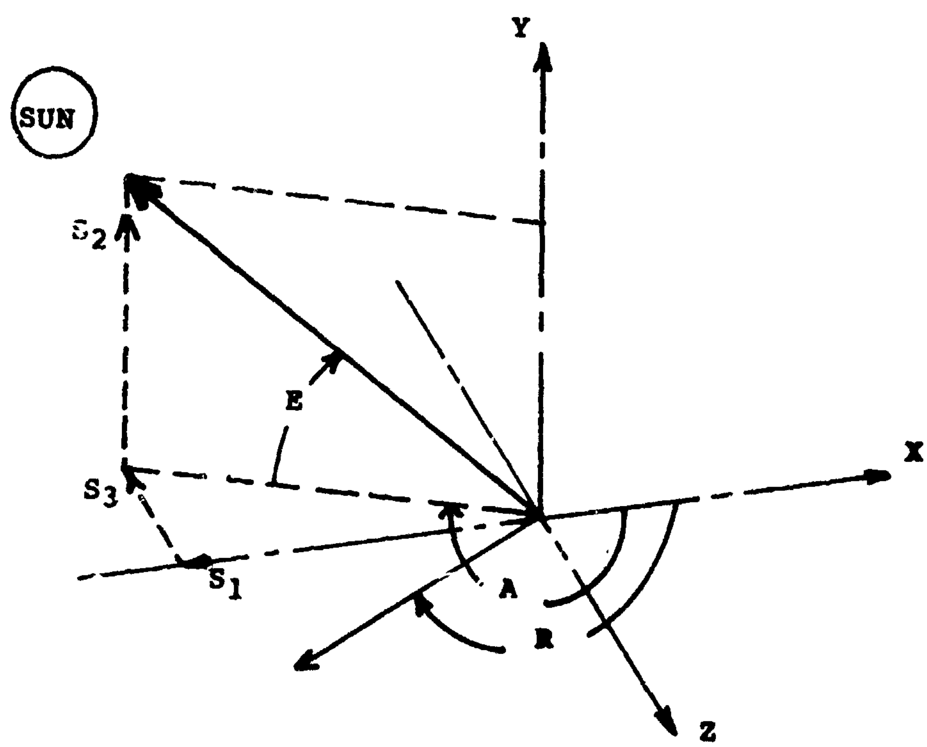

Fig 1 Definition of unit sun vector and range azimuth

The field of view of the yaw sonde is a cone with a 90° apex angle, the axis of the cone being perpendicular to the axis of the projectile. The angle ψ is measured from the nose of the projectile to the sun vector drawn from the yaw sonde position on the projectile's axis. For the yaw sonde to see the sun ψ must lie between 45° and 135°.

From the above descriptions of S, V, and ψ, it may be seen that the angle ψ is given by the scalar product.

$$\cos \psi = S\,V = S_1 V_1 + S_2 V_2 + S_3 V_3$$

Since ψ is known to be 45° and 135° along the two edges of the field of view, it will be practicable to use it as an independent parameter for finding the sun's position (A, E).

We note that E has a known range, hence it is assigned a set of values in 2° steps, from 0° to about 80°. This leaves A as the remaining unknown angle. From Equation 1

$$S_2 = \sin E$$

and

$$A = \arctan (S_3/S_1) \tag{4}$$

Thus A can be calculated if S_1 and S_3 can be found, and this can be done by using the directional cosine law for S,

$$1 = S_1^{\,2} + S_2^{\,2} + S_3^{\,2} \tag{5}$$

in connection with Equation 3. The details of the algebra involved in solving for S_1 and S_3 are given in Appendix A and in the listing for the computer program called YSFIRE, in Appendix B. The above calculations were made for each of the three firing sites in Table 1, at launch, peak, and impact, for 30°, 45°, and 60° QE.

TABLE 1

Geographic details of firing sites

Site	Latitude (North)	Longitude (West)	DLG (hour)	Range Azimuth
China Lake, California	35.75°	117.67°	-.155	248.0
Wallops Island, Virginia	37.83°	75.48°	+.032	128.0
Yuma, Arizona	32.83°	114.25°	-.382	90.0

The punched cards from YSFIRE containing the (A, E) points are sorted and those points discarded that fall outside the solar grid which will be described in the next section.

These results tell where the sun has to be for yaw sonde sightings. The next task is to find when the sun will be at these positions.

Solar Grid Calculations

This second line of computation, to find when the sun is in certain positions, is based on a new type of graph, called a "solar grid." The technique used in Reference 3 was extended to combine on one graph the sun's azimuth and elevation as functions of declination and hour angles for each latitude under consideration, as Figures 2, 3, and 4 show. An array of (A, E) points as functions of D and H was generated and plotted by the computer program named SOLAR, using the equations

$$\sin E = \sin L \sin D + \cos L \cos D \cos H \tag{6}$$

$$\sin A = -\cos D \sin H / \cos E \tag{7}$$

$$\cos A = (\sin D - \sin E \sin L)/(\cos E \cos L) \tag{8}$$

Each line of constant declination (except the solstices) represents two dates, because the sun makes a round trip across this grid each year, as Table 2 indicates.

TABLE 2

Declination and solar meridian passage (LMT) for each day of the year

	JAN		FEB		MAR		APR		MAY		JUN	
	Mer Pass	Dec	Mer Pass	Dec	Mer Pass	Dec	Mer Pass	Dec	Mer Pass	Dec	Mer Pass	Dec
	h m	°	h m	°	h m	°	h m	°	h m	°	h m	°
1	1204	S23.0	1214	S17.1	1212	S7.6	1204	N 4.5	1157	N15.0	1158	N22.0
2	1204	22.9	1214	16.8	1212	7.3	1204	4.9	1157	15.3	1158	22.2
3	1204	22.8	1214	16.6	1212	6.9	1203	5.3	1157	15.6	1158	22.3
4	1205	22.7	1214	16.3	1212	6.5	1203	5.6	1157	15.9	1158	22.4
5	1205	22.6	1214	16.0	1212	6.1	1203	6.0	1157	16.2	1158	22.5
6	1206	S22.5	1214	S15.7	1211	S5.7	1203	N 6.4	1157	N16.5	1159	N22.6
7	1206	22.4	1214	15.3	1211	5.3	1202	6.8	1157	16.8	1159	22.7
8	1207	22.3	1214	15.0	1211	4.9	1202	7.2	1156	17.1	1159	22.8
9	1207	22.1	1214	14.8	1211	4.5	1202	7.5	1156	17.3	1159	22.9
10	1208	22.0	1214	14.4	1210	4.2	1201	7.9	1156	17.6	1159	23.0
11	1208	S21.8	1214	S14.1	1210	S3.8	1201	N 8.3	1156	N17.8	1159	N23.1
12	1208	21.7	1214	13.7	1210	3.4	1201	8.6	1156	18.1	1200	23.1
13	1209	21.5	1214	13.4	1210	3.0	1201	9.0	1156	18.4	1200	23.2
14	1209	21.3	1214	13.1	1209	2[illegible]	1200	9.4	1156	18.6	1200	23.3
15	1209	21.1	1214	12.7	1209	2.2	1200	9.7	1156	18.8	1200	23.3
16	1210	S21.0	1214	S12.4	1209	1.8	1200	N10.1	1156	N19.1	1201	N23.3
17	1210	20.8	1214	12.0	1208	[illegible].4	1200	10.4	1156	19.3	1201	23.4
18	1210	20.6	1214	11.7	1208	[illegible]0	1159	10.8	1156	19.5	1201	23.4
19	1211	20.4	1214	11.3	1208	0.[illegible]	1159	11.1	1156	19.7	1201	23.4
20	1211	20.2	1214	11.0	1208	0.2	1159	11.5	1156	20.0	1201	23.4
21	1211	S19.9	1214	S10.6	1207	N0.2	1159	N11.8	1156	N20.2	1202	N23.4
22	1212	19.7	1214	10.2	1207	0.6	1159	12.2	1157	20.4	1202	23.4
23	1212	19.5	1213	9.9	1207	1.0	1158	12.5	1157	20.6	1202	23.4
24	1212	19.2	1213	9.5	1206	1.4	1158	12.8	1157	20.7	1202	[illegible].4
25	1212	19.0	1213	9.1	1206	1.8	1158	13.1	1157	20.9	1202	23.4
26	1213	S18.7	1213	S 8.8	1206	N2.[illegible]	1158	N13.5	1157	N21.1	1203	N23.4
27	1213	18.5	1213	8.4	1205	2.5	1158	13.8	1157	21.3	1203	23.3
28	1213	18.2	1213	8.0	1205	2.9	1157	14.1	1157	21.4	1203	23.3
29	1213	18.0	1213	7.8	1205	3.3	1157	14.4	1157	21.6	1203	23.2
30	1213	17.7			1205	3.7	1157	14.7	1157	21.8	1203	23.2
31	1213	S17.4			1204	N4.1			1158	N21.9		

	JUL		AUG		SEPT		OCT		NOV		DEC	
	Mer Pass	Dec	Mer Pass	Dec	Mer Pass	Dec	Mer Pass	Dec	Mer Pass	Dec	Mer Pass	Dec
	h m	°	h m	°	h m	°	h m	°	h m	°	h m	°
1	1204	N23.1	1206	N18.1	1200	N8.4	1150	S 3.1	1144	S14.4	1149	S21.8
2	1204	23.1	1206	17.8	1200	8.0	1149	3.5	1144	14.7	1149	21.9
3	1204	23.0	1206	17.5	1159	7.6	1149	3.9	1144	15.0	1150	22.1
4	1204	22.9	1206	17.3	1159	7.2	1149	4.3	1144	15.3	1150	22.2
5	1204	22.8	1206	17.0	1159	6.9	1149	4.7	1144	15.6	1151	22.4
6	1205	N22.7	1206	N16.7	1158	N6.5	1148	S 5.1	1144	S15.9	1151	S22.5
7	1205	22.6	1206	16.5	1158	6.1	1148	5.4	1144	16.2	1151	22.6
8	1205	22.5	1206	16.2	1158	5.7	1148	5.8	1144	16.5	1152	22.7
9	1205	22.4	1205	15.9	1157	5.4	1147	6.2	1144	16.8	1152	22.8
10	1205	22.3	1205	15.6	1157	5.0	1147	6.6	1144	17.1	1153	22.9
11	1205	N22.1	1205	N15.3	1157	N4.6	1147	S 7.0	1144	S17.4	1153	S23.0
12	1205	22.0	1205	15.0	1156	4.2	1147	7.3	1144	17.7	1154	23.1
13	1206	21.9	1205	14.7	1156	3.9	1146	7.7	1144	17.9	1154	23.1
14	1206	21.7	1205	14.4	1156	3.5	1146	8.1	1144	18.2	1155	23.2
15	1206	21.6	1204	14.1	1155	3.1	1146	8.5	1145	18.5	1155	23.3
16	1206	N21.4	1204	B13.8	1155	N2.7	1146	S 8.8	1145	S18.7	1156	S23.3
17	1206	21.2	1204	13.5	1155	2.3	1145	9.2	1145	19.0	1156	23.4
18	1206	21.1	1204	13.2	1154	1.9	1145	9.6	1145	19.2	1156	23.4
19	1206	20.9	1204	12.8	1154	1.5	1145	9.9	1145	19.4	1157	23.4
20	1206	20.7	1203	12.5	1154	1.2	1145	10.3	1146	19.7	1157	23.4
21	1206	N20.5	1203	N12.2	1153	N0.8	1145	S10.6	1146	S19.9	1158	S23.4
22	1206	20.3	1203	11.9	1153	0.4	1145	11.0	1146	20.1	1158	23.4
23	1206	20.1	1203	11.5	1152	S0.0	1144	11.4	1146	20.3	1159	23.4
24	1206	19.9	1202	11.2	1152	0.4	1144	11.7	1147	20.5	1159	23.4
25	1206	19.7	1202	10.8	1152	0.8	[illegible]	12.1	1147	20.7	1200	23.4
26	1206	N19.5	1202	N10.5	1151	S1.2	1144	S12.4	1147	S30.9	1200	S23.4
27	1206	19.3	1202	10.1	1151	1.6	1144	12.7	1148	21.1	1201	23.3
28	1206	19.0	1201	9.8	1151	2.0	1144	13.1	1148	21.3	1201	23.3
29	1206	18.8	1201	9.4	1150	2.4	1144	13.4	1148	21.5	1202	23.2
30	1206	18.6	1201	9.1	1150	2.7	1144	13.7	1149	21.6	1202	23.2
31	1206	N18.3	1200	N 8.7			1144	S14.1			1203	S23.1

The computer program SOLAR also plots on this grid the limit lines obtained from the FIRE program in the previous step, as Figures 2, 3, and 4 show. It is now evident why it was expedient to combine azimuth and elevation on one graph, because this makes it possible to graphically translate the sun's limiting angular (A, E) positions into date and hour (D, H) numbers. This is done by hand, reading off the intersections of each limit line with successive date and hour lines over a complete year cycle. These (D, H) numbers are punched on cards for the final plotting of the year chart.

Many of the limit lines cross the grid from winter to summer solstice. For such lines, a standard set of 22 dates (at every 5° of declination) was established, to expedite the translation to (D, H) numbers, starting with 1 January at 23.0 S declination. This type of limit line transforms to lines that cross the year chart from January to December, e.g., the impact limit for 45° QE in Figure 5.

Other limit lines do not cross the grid, but enter and leave at either solstice. These lines transform to closed loops on the year chart, e.g., the launch limit for 60° QE in Figure 5. In the same figure, the limits for peak and 30° impact also form loops which are interrupted at the year's end.

Year Chart Display

The actual plotting of the (D, H) numbers is done by the computer program YSYEAR. Special calendar year graph paper was obtained expressly for this part of the project.[1] The dates D were changed to day number by reference to Table 3, to fit the dates into the 366 divisions on the long axis of the graph paper.

To produce Civil Standard Time, the local hours H are corrected for Meridian Passage (MP or EMP) and longitude in the YSYEAR program according to the equation

$$CVT = H - EMP + DLG \qquad (9)$$

[1] The special graph paper was taped to the paper on the drum of the Calcomp Plotter, to draw the graph directly on the year paper.

TABLE 3

The number of each day of the year

Day of Mo.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Day of Mo.
1	1	32	60	91	121	152	182	213	244	274	305	335	1
2	2	33	61	92	122	153	183	214	245	[illegible]	306	336	2
3	3	34	62	93	123	154	184	215	246	276	307	337	3
4	4	35	63	94	124	155	185	216	247	277	308	338	4
5	5	36	64	95	125	156	186	217	248	278	309	339	5
6	6	37	65	96	126	157	187	218	249	279	310	340	6
7	7	38	66	97	127	158	188	219	250	280	311	341	7
8	8	39	67	98	128	159	189	220	251	281	312	342	8
9	9	40	68	99	129	160	190	221	252	282	313	343	9
10	10	41	69	100	130	161	191	222	253	283	314	344	10
11	11	42	70	101	131	162	192	223	254	284	315	345	11
12	12	43	71	102	132	163	193	224	255	285	316	346	12
13	13	44	72	103	133	164	194	225	256	286	317	347	13
14	14	45	73	104	134	165	195	226	257	287	318	348	14
15	15	46	74	105	135	166	196	227	258	288	319	349	15
16	16	47	75	106	136	167	197	228	259	289	320	350	16
17	17	48	76	107	137	168	198	229	260	290	321	351	17
18	18	49	77	108	138	169	199	230	261	291	322	352	18
19	19	50	78	109	139	170	200	231	262	292	323	353	19
20	20	51	[illegible]	110	140	171	201	232	263	293	324	354	20
21	21	52	80	111	141	172	202	233	264	294	325	355	21
22	22	53	81	112	142	173	203	234	265	295	326	356	22
23	23	54	82	113	143	174	204	235	266	296	327	357	23
24	24	55	83	114	144	175	205	236	267	297	328	358	24
25	25	56	84	115	145	176	206	237	268	298	329	359	25
26	26	57	85	116	146	177	207	238	269	299	330	360	26
27	27	58	86	117	147	178	208	239	270	300	331	361	27
28	28	59	87	118	148	179	209	240	271	301	332	362	28
29	29	*	88	119	149	180	210	241	272	302	333	363	29
30	30		89	120	150	181	211	242	273	303	334	364	30
31	31		90		151		212	243		304		365	31

* In leap years, after February 28, add 1 to the tabulated number.

The MP figures are obtained from Table 2 and converted to hours before reading into the program, thus

$$EMP = (MP - 12)/60$$

The MP is the local mean time at which the sun crosses the meridian at any given site. Throughout the year it varies from +15 to -15 minutes.

The correction for longitude, DLG, converts local time to civil time, i.e., the clock time in the particular time zone where the firing site is situated. The limit lines plotted by YSYEAR are shown in Figures 5, 6, and 7.

Trajectory Heights at Different Terminal Slopes

A preliminary review of the windows for the different quadrant elevations in Figures 5, 6, and 7 showed that the 60° quadrant elevations are the most restricted, but they are also the trajectories that are of the greatest interest. Since the descending branch of a trajectory seems to be less important than the ascending it may be worth estimating how much of a trajectory is recorded if the projectile is fired at some time point in the obscured region for the actual quadrant elevation. That is, how much of a 60° trajectory will be recorded if it is fired at a point on the impact limit for, say, a 45°trajectory. This may widen somewhat the windows for the steeper trajectories, if part of the descending portion can be disregarded. A few calculations have been made to investigate this possibility, assuming symmetrical parabolic trajectories.

From elementary mechanics, the equation for a parabolic trajectory with origin at the launch point, is

$$y = x \tan Q - gx^2/(2v^2 \cos^2 Q)$$

The range is

$$r = (2v^2/g) \sin Q \cos Q$$

and the maximum height is

$$h = (v^2/2g) \sin^2 Q$$

Through suitable manipulations, the velocity is eliminated and dimensionless height and range coordinates are introduced, giving

$$y/h = (4/r)(x - x^2/r)$$

The problem now is to find the height at which a given trajectory has a smaller slope than its initial quadrant elevation. This is done by differentiating the above equation, which gives

$$y'/h = (4/r)(1 - 2x/r)$$

where y' is the slope at height h. Eliminating the dimensionless range, we find

$$y/h = 1 - (ry'/4h)^2 = 1 - (y' \cot Q)^2$$

where $r/4h = \cot Q$ and y' is the arbitrarily chosen smaller slope.

Table 4 shows the results for three simple cases encountered in this project.

TABLE 4

Heights at early cutoffs

Quadrant Elevations	y'	y/h
60°	45°	2/3
60°	30°	8/9
45°	30°	2/3

A projectile fired at a time point on the impact limit curve for y' will go beyond the peak to the above fraction of h before the sun disappears from the yaw sonde. Conversely, a projectile fired at a point on the launch limit curve for y' will not see the sun until it reaches the above height on the ascending segment of the curve. All projectiles fired at time points on the peak curves will either cut off there, if in the terminal region, as in Figures 5 and 6 and the upper part of Figure 7, or will start only at the peak, as in the launch region of Figure 7.

RESULTS

The results obtained in this study are the solar grids and year charts for each of the three sites, Figures 2 through 7 inclusive. Table 4 shows the height at which early cutoffs in steep trajectories occur.

DISCUSSION

Limit Lines

The procedure in YSFIRE for calculating the limit points (A, E) leaves out the positive identification of the visible side of the boundary. This identification is fairly evident from past experience and from the geometry of the firing range situation. In ambiguous cases the visible side was identified by using γ values of 50° and 130° in Equation 3 and noting to which side of the original A points the new A points fall for the same E values.

In general, the limit lines may have minima and maxima in the solar grid region, i.e., there may at some places be two different A values for a single E value for a given quadrant elevation line. This possibility is anticipated in the YSFIRE program. A corollary to this is the requirement that all limit lines enter and exit the grid somewhere; they dare not end inside the grid.

The effect of the actual yawing of a projectile would be to widen the limit lines into bands. To delineate such bands for a given yaw angle, say 5°, one would use in Equation 3 four values of γ, namely, 45° ± 5° and 135° ± 5°. This would produce a pair of A values for

each E. When the two sides of a band are transcribed to (D, H) values a corresponding band would be produced on the year chart. But the width of any such band is not easily estimated. In practice, if one fires too close to a limit line, periodic breaks will occur in the yaw sonde record when the angle γ exceeds its limits during projectile precession about the velocity vector.

Site Parameters

Two site parameters that affect the results are range azimuth and latitude. We will discuss first the azimuth, which has the greatest effect. This parameter has nearly its maximum possible spread of 90° in this study. It influences the A values in the (A, E) limit points, as can be seen in Figures 2, 3, and 4, where the latitude spread is only 5°. When these limit lines are translated to the year charts the resulting windows present very different appearances. The nearly north-south azimuth at China Lake provides the widest windows, whereas the east-west azimuth at Yuma provides the narrowest windows. As the latitude has a different sort of effect one may infer that north-south azimuths will always yield wider windows.

If new firing sites are contemplated they should be located where nearly north-south range azimuths are available, since the range azimuth at any particular site is rather permanently and narrowly limited by geographic and demographic restrictions, and cannot be changed to suit the convenience of ordnance experimenters.

It is also interesting to note that, if one fires a projectile in the opposite sense along a given range line, the curves on the solar grids and year charts will be the same, except that the launch and impact labels will be interchanged.

The other site parameter, latitude, has less influence on the limit lines, through its effect on the solar grid. On all grids the equinox line (0° declination) always passes through the sunrise and sunset lines at 90° and 270° azimuth, respectively. At noon it passes through an elevation equal to the colatitude (90° - L). Thus, all grids have the same width, but lower maximum heights for higher latitudes. The latitude effect for a given range azimuth may be estimated by imagining that the limit lines for one latitude are drawn on the grid for another latitude. Because the slopes and shapes of the limit lines

themselves differ, each quadrant elevation line would have to be studied in detail, a tedious procedure not warranted in this study. In general, it may be inferred that change in latitude will change slightly the sizes and shapes, but not the topology, of the yaw sonde windows.

Year Charts

The limit lines on the year chart are almost symmetrical if reflected about the summer or winter solstice, and they would be exactly symmetrical if it were not for the MP correction, which fluctuates during the year. The MP has a different phase from the sun and has two different periods and amplitudes. The maximum variation is from +15 minutes in February to -15 in November. This produces a "vertical shear" in the lines, between 3 November and 8 February, on which days the sun has the same declination (15 S).

The sunrise, sunset, and peak limits are common to all trajectories, regardless of their initial quadrant elevation. The peak limit is the same as that of a flat trajectory. Starting with this QE of 0° and proceeding through 30°, 45°, and 60° quadrant elevations, one can see on any year chart successive decreases in visibility. The steepest trajectory has the smallest window at any site.

The windows for the steeper trajectories can be extended somewhat by firing at time points outside their visibility area, if one is content to lose part of either the ascending or descending branch.

How to Read the Year Charts

The limit lines are labelled with quadrant elevation symbols identified in the legend near the right side of each chart. In these charts and in the solar grids, the letter T is used for "Terminal" in place of I for "Impact" because the symbol I is too easily mistaken for a number 1. Lettering in certain areas states which segments -- launch, peak, or impact -- are invisible for all quadrant elevations surrounding the lettering. Other segments and quadrant elevations are visible in such areas. On the Wallops Island chart, the launch segments are visible above the lines labelled "Launch Limits." On the Yuma chart, all launches are visible above the lower group of lines, and the impacts are visible below the upper group, e. g. at Yuma the 60° launches (60 L) are visible only after 1235 hr, and the 60° impacts, 60 T, before 1030 hr, in midsummer.

Individual Sites

China Lake offers the largest windows. All launches are visible all year at any time of day, except for a short period for the 60° launch (60 L) around noon in midsummer. Impacts are invisible over the noon hour all year, except for 0° and 30° during the summer.

Wallops Island presents a simpler pattern. All launches are visible after 1330 in the summer and noon in the winter. Impacts are visible between September and April in the afternoons, but between April and September the peak cuts off at 1620 hours and the steeper trajectories cut off at earlier times.

Yuma offers the smallest windows; here, the only open spot for all trajectories is from 0900 to 1400 hours from November to February. The peak is clear between 0800 and 1500 hours all summer. The launch segments for the other quadrant elevations are visible after 1030 or 1230 hours, and the impacts are visible before 1230 or 1030 hours.

These charts are offered as a rough guide for selecting suitable firing times. It is not recommended that firings be made at times too close (say 15 minutes) to the limit lines, for reasons mentioned earlier in the Discussion.

CONCLUSIONS

It is practicable to plot year charts of yaw sonde windows for any given site and range azimuth. The windows are widest for north-south azimuths (China Lake) and narrowest for east-west azimuths (Yuma). The steepest trajectories have the narrowest windows. At the three sites studied, it is possible to obtain yaw sonde records for all trajectories at some time during the year.

RECOMMENDATIONS

To expedite scheduling of firing programs, the year charts submitted here should be consulted.

When new yaw sonde firing sites are chosen, preference should be given those whose range azimuths are most nearly parallel to the local meridian.

REFERENCES

1. Amery, Henning, Lawrie, Wlatnig, "Telemetry System for Measurement of Yaw of a Projectile Throughout the Major Part of its Trajectory," RARDE, Guns and Ammunition Division, Report 1/65, March 1965

2. LaCombe, Gordon, "A Method for the Determination of Optimum Launch Time for Missiles Carrying Sun Sensors," Naval Weapons Center, Technical Publication No. 4179, March 1967

3. Doan, L. Capt., and Sandford, B., "Solar Elevation, Depression, and Azimuth Graphs," Air Force Cambridge Research Laboratories, Report 70-0086, Environmental Research Papers No. 313, February 1970

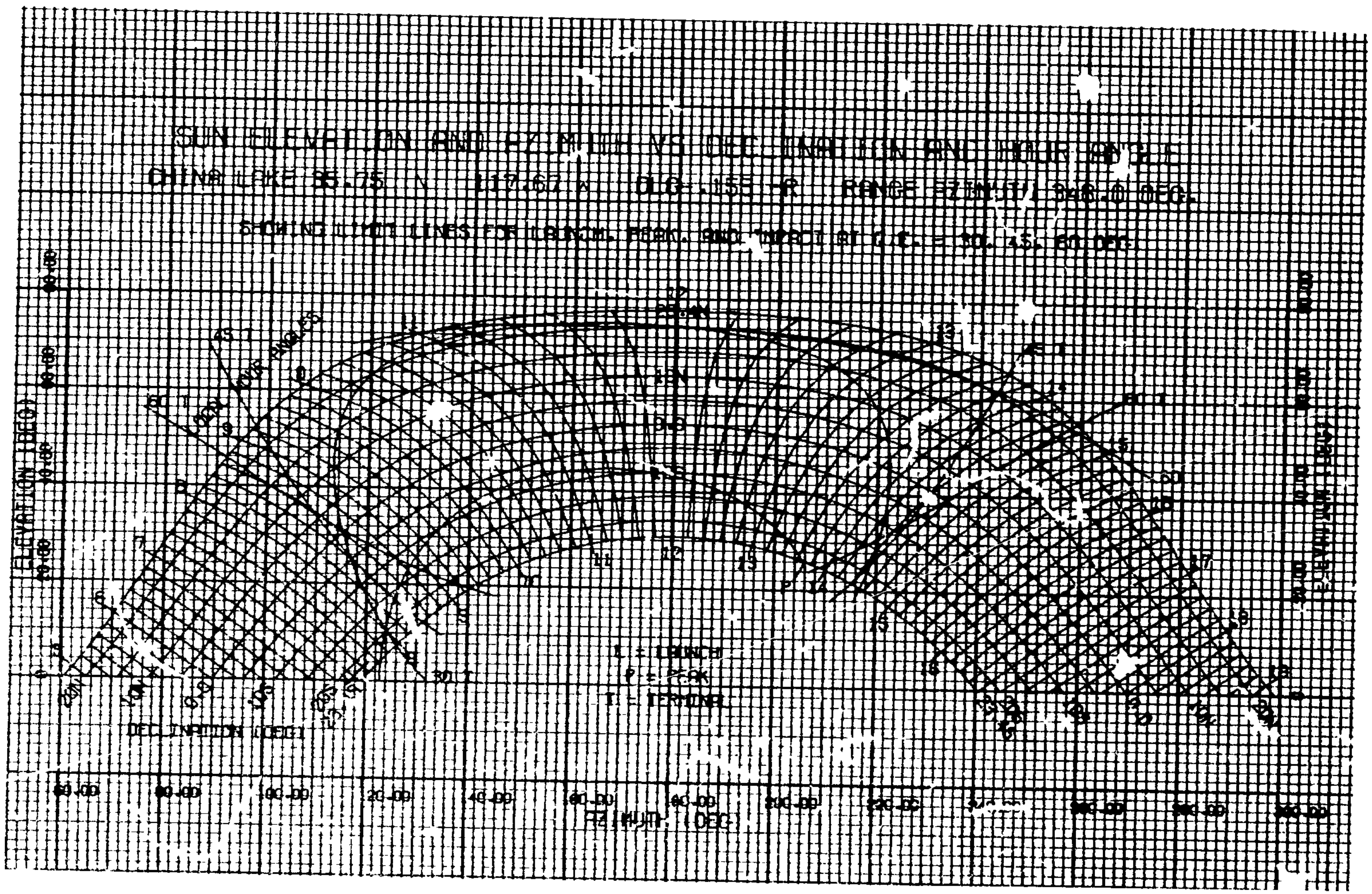

Fig 2 Solar grid for China Lake

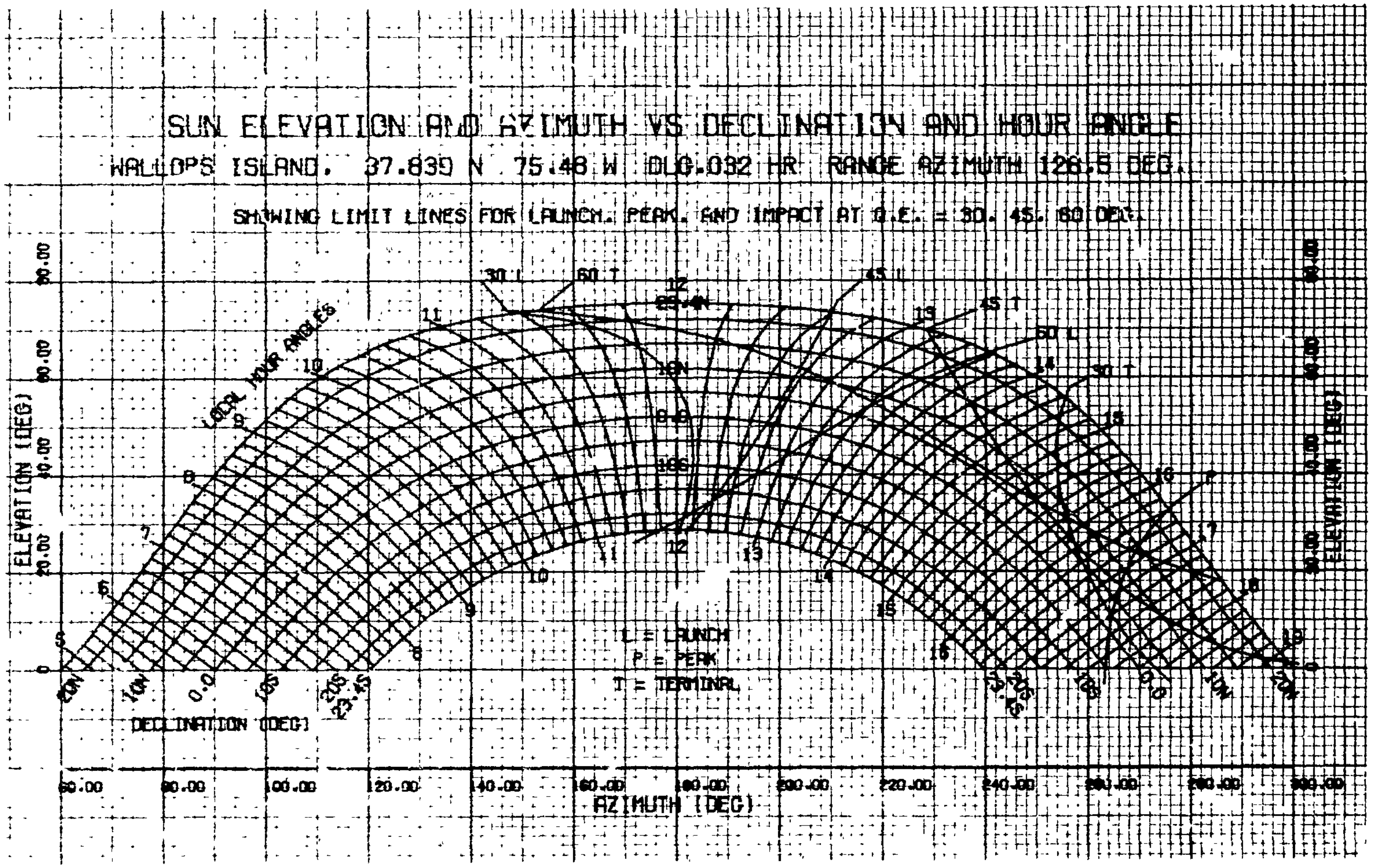

Fig 3 Solar grid for Wallops Island

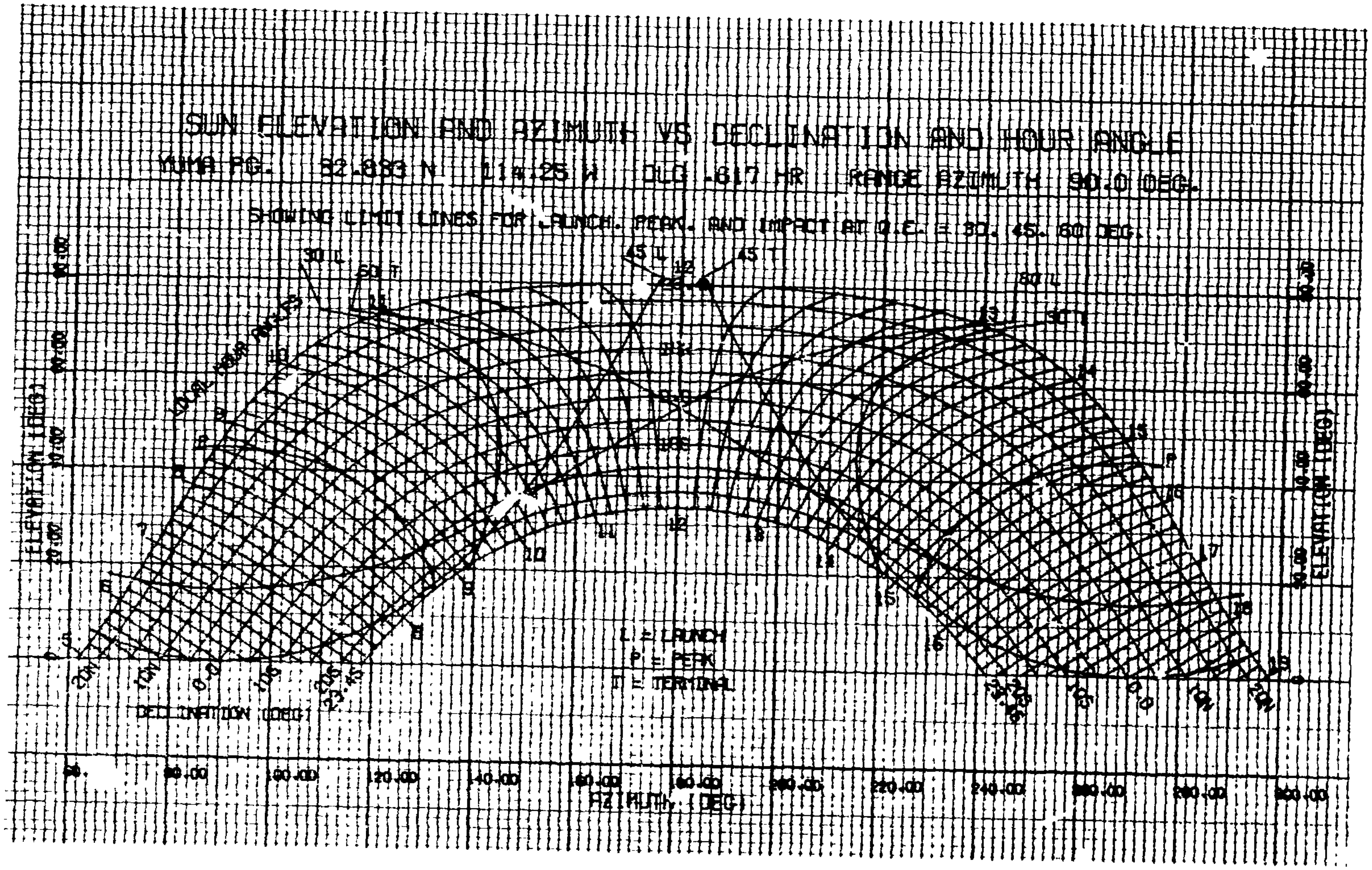

Fig 4 Solar grid for Yuma

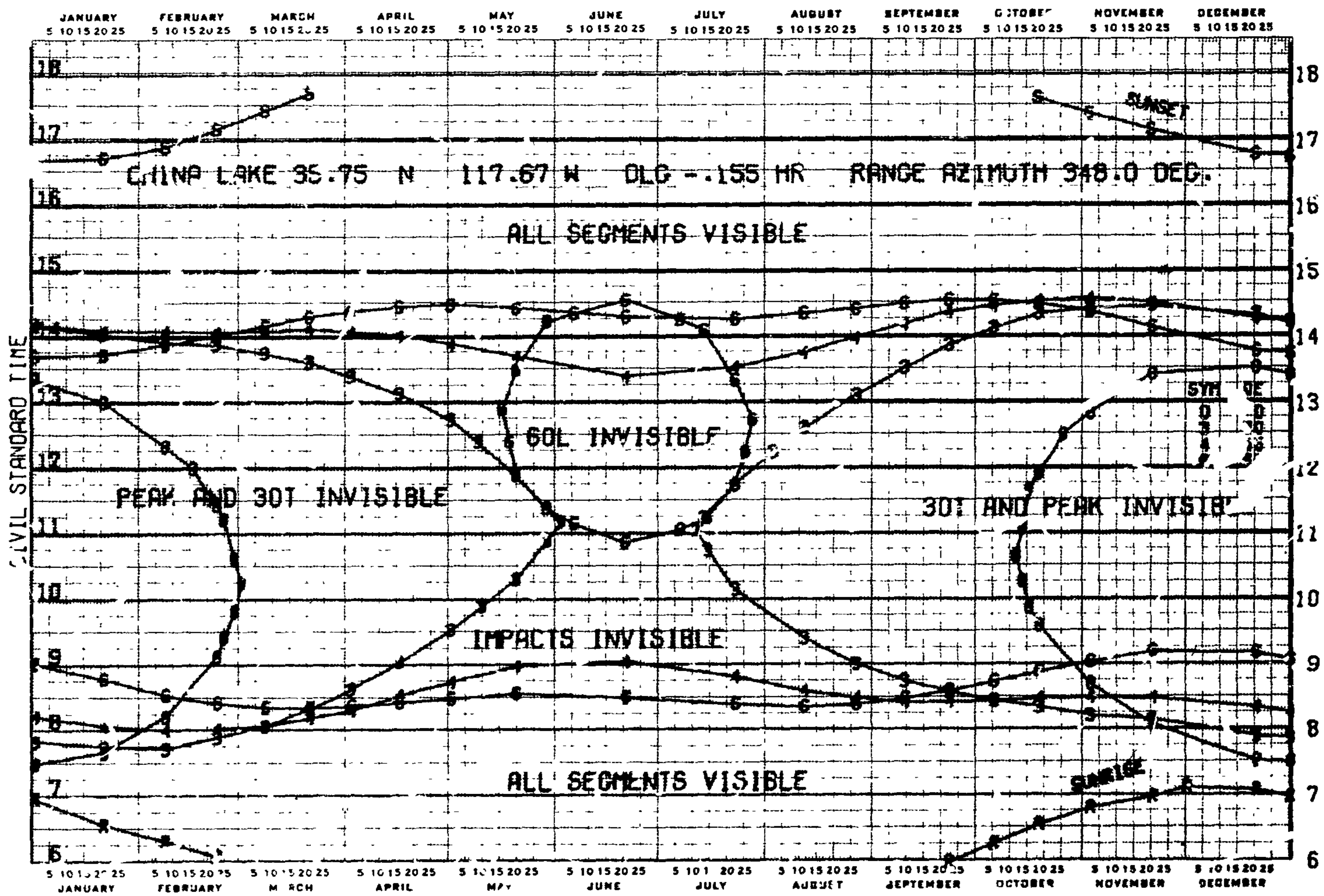

Fig 5 Year chart for China Lake

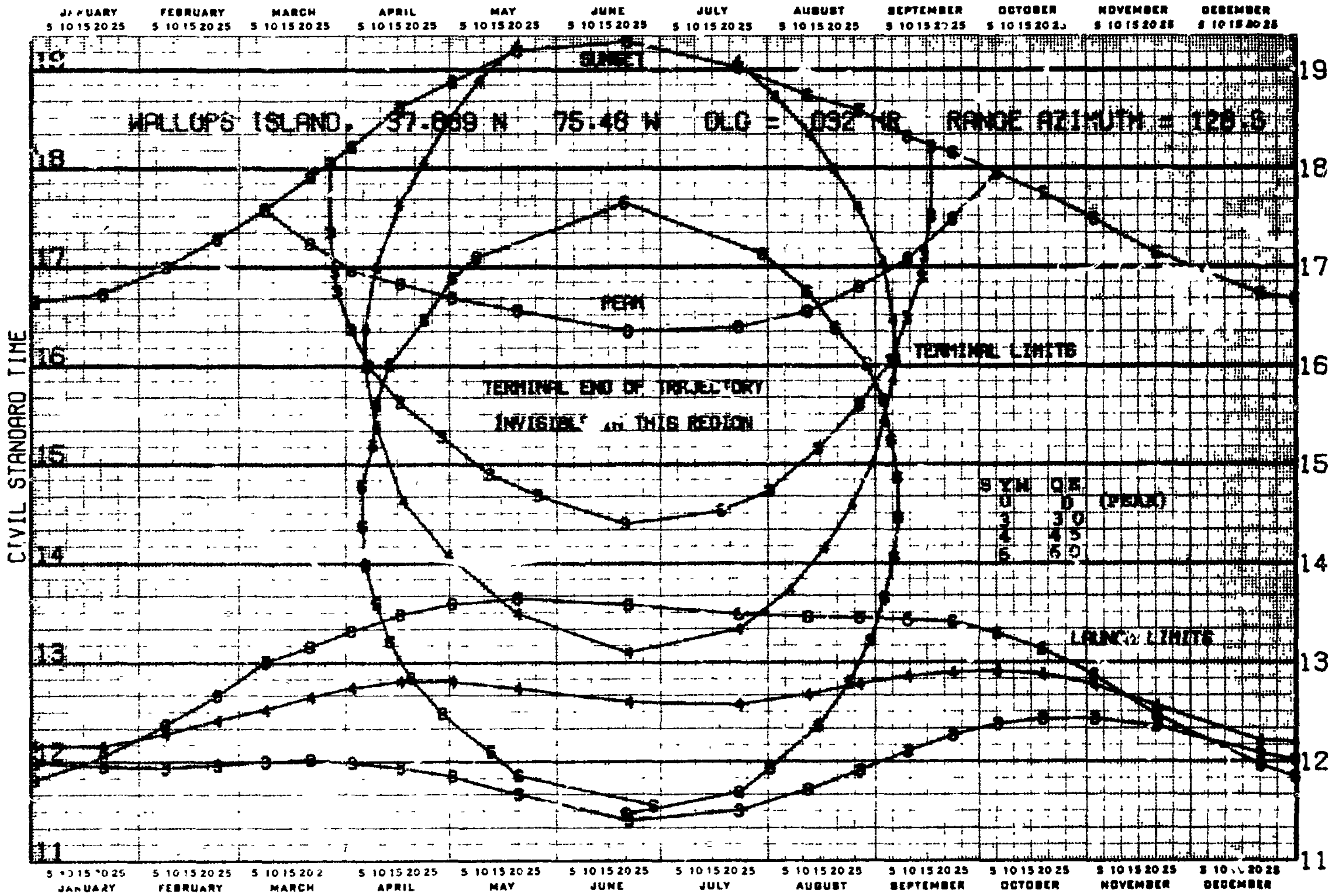

Fig 6 Year chart for Wallops Island

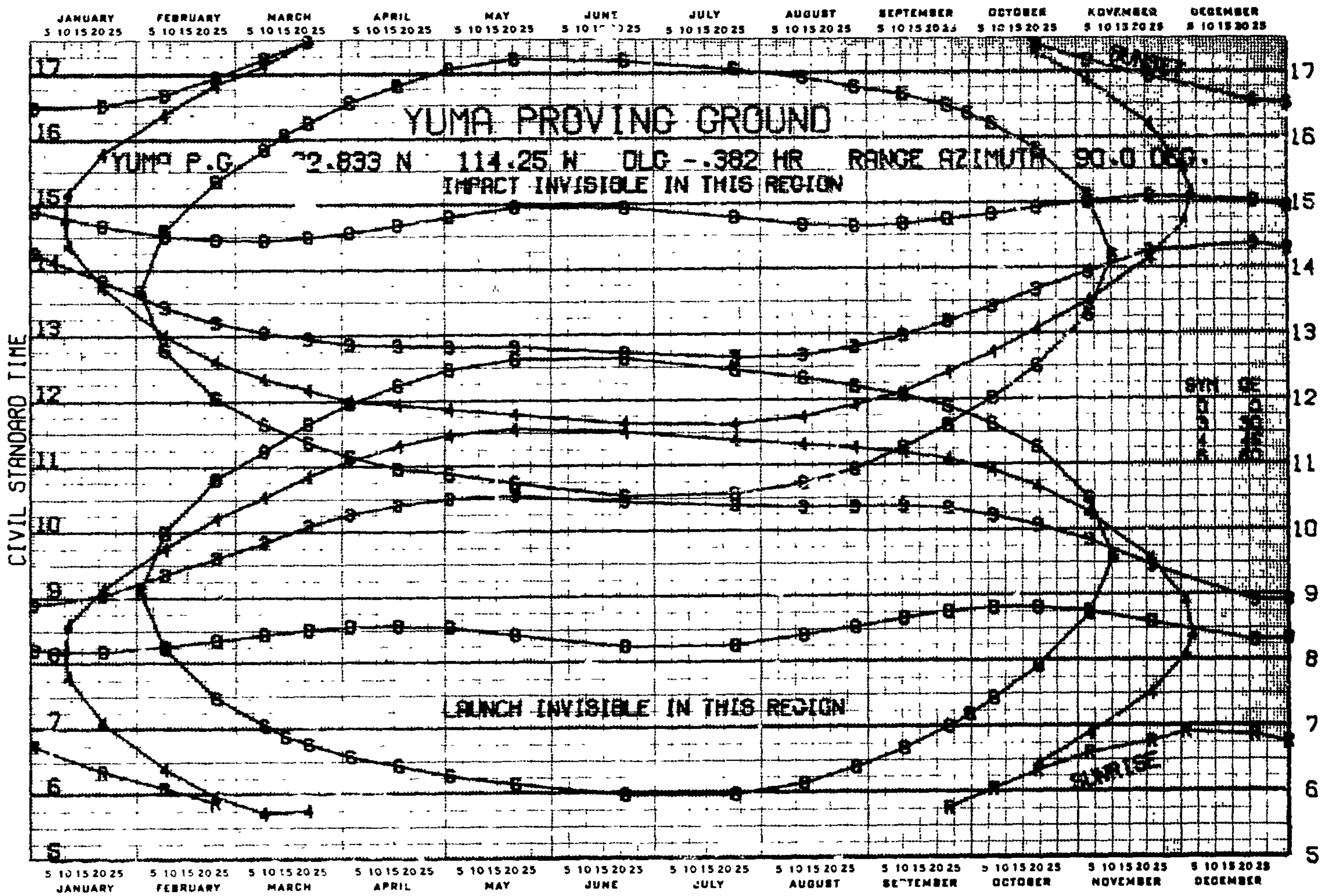

Fig 7 Year chart for Yuma

APPENDIX A

Algebraic details of the solution for S_1 and S_3

Elimination of S_3 from Equations 3 and 4 gives

$$S_1^2(V_1^2 + V_3^2) - 2S_1V_1(P - EV_2) + (P - EV_2)^2 \quad V_3^2(1 - E^2) = O$$

The solution for S_1 is

$$S_1 = \frac{V_1(P - EV_2)}{V_1^2 + V_3^2}\left[1 \pm \left(1 - \frac{(V_1^2 + V_3^2)(P - EV_2)^2 - V_3^2(1-E^2)}{(V_1(P - EV_2))^2} \right)^{1/2} \right]$$

Then

$$S_3 = (P - EV_2 - S_1V_1)/V_3$$

When the range azimuth points toward any one of the four cardinal points of the compass, special cases arise because either S_1 or S_3 become zero. At Yuma, for instance, where $R = 90°$ and $V_1 = O$,

$$S_3 = (P - EV_2)/V_3$$

and

$$S_1 = \pm \left(1 - E^2 - S_3^2\right)^{1/2}$$

Although these solutions are straightforward for hand computation, many branchings must be anticipated for machine computation, as the listing for YSFIRE in Appendix B shows. The possibility of two A values for a single E value is also provided for, by including BAS1 and BAS2 among the answers when punched.

Because of the way the program is arranged, the punched cards are a mixture of different stages for a single quadrant elevation; however, they are easily sorted out manually to produce continuous limit curves on the solar grid.

APPENDIX B

Program Listings

YSFIRE
SOLAR
YSYEAR

```
C
      PROGRAM YSFIRE(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,PUNCH,
     + TAPE7=PUNCH)
C
C              PROGRAM TO CALCULATE OPTIMUM LAUNCH TIMES FOR YAW SONDE.
C
      INTEGER DYN
C
      DIMENSION MON(22),             SHA(3),CVT(3),PSI(3,3),EMP(22),QE(3)
     +,V(3,3),S(3,3),SITE(8),ASH(3),LSH(3),LSC(3),LSM(3),LCM(3),A(3),
     + B(3),AZ(3),PS(3),ES(44),AQ(3,2,2)
C
  100 FORMAT (1H1)
  101 FORMAT (8A10)
  102 FORMAT (12F6.0)
  103 FORMAT (12I6)
  104 FORMAT (/44X,47H OPTIMUM FIRING TIMES FOR YAW SONDE TESTS       )
  105 FORMAT (/21X,6HLAUNCH,5X,4HPEAK,4X,8HTERMINAL/22X,2HAS,6X,2HES,6X
     +,3HLHA,5X,3HCVT/)
  106 FORMAT ( 6X,A6,   5X,2F8.1,F9.2,I5,I3)
  107 FORMAT (13X,3HPSI,3F10.1/)
  108 FORMAT (//35X,59HCALCULATION OF SUN AZIMUTH FOR GIVEN PSI AND SUN
     +ELEVATION ,12H  FOR Q.E. =,F5.1/)
  109 FORMAT ( 9X,A8,20X,30H NO SOLUTION, IMAGINARY ROOTS.  )
  110 FORMAT ( 9X,A8,20X,  35H NO SOLUTION, SUN IN WRONG QUADRANT  )
  111 FORMAT (4X,3HPSI,16X,2HS2,8X,2HSP,8X,2HSM,8X,2HS1,8X,2HS3, 8X,
     +  3HASP,8X,3HASM,7X,3HAQ1,7X,3HAQ2,7X,7HQ.E. = ,F4.1)
  112 FORMAT(/9X,10HELEVATION ,F5.1,32X, 5HS2 = ,F7.5,        44X,F5.1)
  113 FORMAT (4X,F4.0,1X,A8,5F10.5,4F10.1)
  114 FORMAT (12X,2F8.4,20X,2I4,4X,I4)
  115 FORMAT(/30X,72HVERIFICATION OF PSI VALUES PRIOR TO PLOTTING LIMIT
     +CURVES ON YEAR CHART   /)
  116 FORMAT (1H1,55X,25HTWENTY-TWO STANDARD DATES,30X, 6HQ.E. =,F5.1/
     +35X,57HPSI MINIMUM = 45 DEG., EARLIEST TIMES TO FIRE            /
     6 60X,5HNST =,I2)
  117 FORMAT (1H1,50X,18HINTERMEDIATE DATES    ,30X,6HQ.E. =,F5.1/
     +35X,44HPSI MAXIMUM = 135 DEG., LATEST TIMES TO FIRE       /
     7 60X,5HNST =,I2)
  118 FORMAT ( A6,F6.0,4F8.0,4I4)
  119 FORMAT (20X,6HBAS1 =,F7.1,10X,6HBAS2 =,F7.1)
 1004 FORMAT ( 1H1 // 45X , 32HENGINEERING SCIENCES LABORATORY /10X,A10,
     C 30X, 23H AEROBALLISTICS BRANCH   )
C
      DATA MON/6HJAN  1,6HJAN 21,6HFEB  8,6HFEB 23,6HMAR  8,6HMAR 21,
     A 6HAPR  2,6HAPR 15,6HMAY  1,6HMAY 20,6HJUN 21,6HJUL 23,6HAUG 12,
     B 6HAUG 27,6HSEP 10,6HSEP 23,6HOCT  6,6HOCT 19,6HNOV  3,6HNOV 21,
     C 6HDEC 21,6HDEC 31/
C
      DATA AZ/8H LAUNCH ,8H  PEAK  ,8H IMPACT /
C
      DATA EMP/0.0667,0.1833,0.2333,0.2167,0.1833,0.1167,0.0667,0.0,
     A-0.05,-0.0667,0.0333,0.10,0.0833,0.0333,-0.05,-0.1333,-0.20,
     B-0.25,-0.2667,-0.2333,-0.0333,0.0333/
C
C       DLG = LONGITUDE DIFFERENCE, POS WHEN SITE IS WEST OF ZONE CENTER.
```

```
C        EMP = MERIDIAN PASSAGE MINUS 12.
C
C        MC = 0  TO CALCULATE PSI
C        MC = 1  TO CALCULATE AZIMUTH FROM GIVEN PSI AND ELEVATION
C        NPCH = 1 TO PUNCH A.E ON CARDS.
C
      RADN = 57.29578
      NC = 0
      CALL DATE(JD)
      WRITE (6,1004) JD
      WRITE (6,104)
      READ (5,101) SITE
      READ (5,102) ATU,DLG,RAZ
      READ (5,103) MC,NCRV,KLT,NPCH
      RAZ = RAZ/RADN
      WRITE (6,101) SITE
      IF (MC.EQ.1) GO TO 200
      WRITE (6,115)
      INLE = 22
C
  200 READ (5,102) (QE(L),L=1,3)
      IF (EOF(5).NE.0 ) GO TO 201
      MQ = QE(1)
C
  202 DO 9 L = 1,3
      QER = QE(L)/RADN
      V(L,1) = COS(QER   )*COS(RAZ)
      V(L,2) = SIN(QER   )
    9 V(L,3) = COS(QER   )*SIN(RAZ)
C
      IF (MC.EQ.0) GO TO 21
C
C     AZIMUTH AND ELEVATION COORDINATES FOR GIVEN PSI LIMITS AT LAUNCH.
C          PEAK, AND IMPACT.
C
      WRITE (6,108)  QE(1)
      WRITE (6,111)  QE(1)
      INLE = 14
      PS(1) =  45.
      PS(2) = 135.
C
      DO 37 K=1,KLT
      ES(K) = 2.0 * (K - 1)
      ESR = ES(K)/RADN
      S2 = SIN(ESR)
      WRITE (6,112) ES(K) , S2, ES(K)
      S1 = 0.0
      S3 = 0.0
      AS = 0.0
      ASP= 0.0
      ASM= 0.0
C
      DO 33 J=1,2
      JSP = PS(J)
      DO 35 I=1,3
```

```
      IF (I.EQ.1.AND.MQ.EQ.30) GO  TO 35
      IF (I.EQ.2.AND.MQ.NE.60) GO  TO 35
      L = I
      VA = V(L,1)
      VB = V(L,2)
      VC = V(L,3)
C
      R = COS(PS(J)/RADN)-S2*VB
      RV = R*VA/(VA*VA + VC*VC)
      Q = 1.0 - S2*S2
C
      IF(RAZ.EQ.90.0.OR.RAZ.EQ.270.0) GO TO 211
      IF(RAZ.EQ. 0.0.OR.RAZ.EQ.180.0) GO TO 212
C
      P = (R*R - Q*VC*VC)/(RV*R*VA)
      RT= 1.0 - P
      IF (RT.GT.0.0) GO TO 22
      WRITE (6,109) AZ(I)
      GO TO 35
C
   22 RT = SQRT(RT)
      SZ = RV
      SP = RV*(1.0 + RT)
      SM = RV*(1.0 - RT)
      IF (RT.EQ.0.0) GO TO 27
C
C         S3 HAS OPPOSITE SIGNS IN TRIGONOMETRIC AND GUNNERY FRAMES.
C
   26 S3P =-(R - VA*SP)/VC
      S3M =-(R - VA*SM)/VC
      ASPR = RADN*ATAN2(S3P,SP)
      IF (ASPR .GE.0.0)   ASP    = 360.0 - ASPR
      IF (ASPR.LT.0.0)   ASP = - ASPR
      AQ(I,J,1) = ASP
      ASMR = RADN*ATAN2(S3M,SM)
      IF (ASMR .GE.0.0)   ASM    = 360.0 - ASMR
      IF (ASMR.LT.0.0)   ASM = - ASMR
      AQ(I,J,2) = ASM
      GO TO 29
C
   27 S1 = SZ
      S3 = - (R - VA*S1)/VC
      AS = RADN*ATAN2(S3,S1)
      IF (AS.GE.0.0) AS = 360. - AS
      IF (AS.LT.0.0) AS = - AS
      AQ(I,J,1) = AS
      AQ(I,J,2) = AS
      GO TO 29
C
  211  S3 = - R/VC
      S1 = Q - S3*S3
      IF (S1.GT.0.0) GO TO  210
      WRITE (6,109)  AZ(I)
      GO TO 35
  210  S1 = SQRT(S1)
```

```
          AS  = ATAN2(S3,S1)  * RADN
          AS2 = ATAN2(S3,-S1)  * RADN
          GO TO 213
C
      212 S1 = R/VA
          S3 = Q - S1*S1
          IF (S3.GT.0.0) GO TO  220
          WRITE (6,109)  AZ(I)
          GO TO 35
      220  S3 = SQRT(S3)
          AS1 = ATAN2( S3,S1)     * RADN
          AS2 = ATAN2(-S3,S1)   * RADN
C
      213 IF (AS1.GE.0.0)  AS1 = 360.0 - AS1
          IF (AS1.LT.0.0)  AS1 =        - AS1
          IF (AS2.GE.0.0)  AS2 = 360.0 - AS2
          IF (AS2.LT.0.0)  AS2 =        - AS2
          AQ(I,J,1) = AS1
          AQ(I,J,2) = AS2
C
       29 CONTINUE
          WRITE (6,113) PS(J),AZ(I),SZ,SP,SM,S1,S3,ASPR,ASMR,AQ(I,J,1)
         W ,AQ(I,J,2)
          INLE = INLE + 1
C
          BAS1 = AQ(I,J,1)
          BAS2 = AQ(I,J,2)
          IF (BAS1.LT.60.0.OR.BAS1.GT.300.0)  GO TO 35
          IF (BAS2.LT.60.0.OR.BAS2.GT.300.0)  GO TO 35
          WRITE (6,119) BAS1,BAS2
          INLE = INLE + 1
          IF (NPCH.EQ.0)  GO TO 35
          WRITE (7,114)BAS1,ES(K),I,MG,JSP
          WRITE (7,114)BAS2,ES(K),I,MG,JSP
C
       35 CONTINUE
       33 CONTINUE
          INLE = INLE + 2
          IF (INLE.LT.58) GO TO 37
          WRITE (6,100)
          WRITE (6,111)  QE(I)
          INLE = 5
       37 CONTINUE
          WRITE (6,100)
          GO TO 200
C
       21 CONTINUE
C
C   VERIFICATION OF SUN-VELOCITY ANGLE, PSI, ALONG LIMIT CURVES.
C
       50 M = 1
       51 READ (5,118) DYN,DUN,BAS,BES,BSHA,BMP,LP,KTP,MOP,NSP
          JF = 0
          IF (EOF(5).NE.0) JF = 1
          IF (JF.EQ.1)  GO TO 12
```

```
C
      NST = NSP
      KTG = KTP
      IF (M.GT.1) GO TO 49
C
      IF (NST.EQ.1)  GO TO 7
    6 WRITE (6,116) QE(1),NST
      GO TO 8
    7 WRITE (6,100)
      INLE = 1
      WRITE (6,117) QE(1),NST
    8 WRITE (6,105)
C
   49 S(1,1) = COS(BES/RADN)*COS(BAS/RADN)
      S(1,2) = SIN(BES/RADN)
      S(1,3) = COS(BES/RADN)*SIN(BAS/RADN)
C
      DO 53 L=1,3
      DO 52 I=1,3
      A(I) = S(1,I)
   52 B(I) = V(L,I)
C
      CALL ANU(A,B,PSI(L))
      PSI(L) = RADN*PSI(L)
   53 CONTINUE
C
C        CIVIL TIME  CALCULATED FROM LOCAL HOUR ANGLE , MERIDIAN PASSAGE,
C                AND DLG FOR EACH DATE
C
      IF (NST.EQ.1) GO TO 54
      BCVT = BSHA - EMP(M) + DLG
      GO TO 55
   54 BCVT = BSHA - EMP + DLG
   55 LSHB = BCVT
      LSCB = LSHB * 100
      LSMB = BCVT * 100 - LSCB
      LCMB = LSMB*60/100
C
      IF (NST.EQ.0) DYN = MON(M)
      WRITE (6,106) DYN,BAS,BES,BSHA,LSHB,LCMB
      WRITE (6,107)  (PSI( L),L=1,3)
      INLE = INLE + 3
      IF (INLE.LT.64)  GO TO 16
      WRITE (6,100)
      INLE = 4
C
   16 M = M + 1
      GO TO 51
   12 NC = NC + 1
      IF (NC.GE.NCRV)  GO TO 201
      IF (KTG.EQ.2.AND.JF.EQ.1)  GO TO 200
      GO TO 50
C
  201 STOP
      END
```

```
C
      SUBROUTINE ANU(V1,V2,THETA)
C
CANU        ANGLE BETWFEN TWO UNIT VECTORS
C
      DIMENSION V1(3  ),V2(3  )
C
      DP=V1(1)  *V2(1)  +V1(2)  *V2(2)  +V1(3)  *V2(3)
      THETA = ACOS(DP)
    5 RETURN
      END
```

```
      PROGRAM  SOLAR(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT)
C
C        PLOTS YAW SONDE LIMIT LINES ON SOLAR GRID FOR GIVEN LATITUDE AND
C                             RANGE AZIMUTH.
C
C              WALLOPS ISLAND CURVES.
C
      DIMENSION D(11),SNH(81),CSH(81),A(12,82),E(12,82),DEC(11),HR(17),
     + AA(81),EE(81),SITE(8),ES (80),AS (80),          AZ(3),JQ(61),
     2 KB(11),KE(11),BQ(2)
C
  100 FORMAT (12F6.0)
  101 FORMAT(/55X,21H LOCAL   HOUR   ANGLES  /12X,13(7X,A2))
  102 FORMAT (7X,14H DECLINATION =, A5,4X,4HKBT=,I3,4X,4HKET=,I3,4X,4HNK
     + =,I3,6X,4HJ   =,I3,6X,3HJQ=,I3   /3X,9HELEVATION, 9F9.4/
     + 3X,9H AZIMUTH , 9F9.4/)
  103 FORMAT ( 2X,8A10)
  104 FORMAT (5X,7H SINE H,13F9.4/)
  105 FORMAT (/33X,54H SUN ELEVATION AND AZIMUTH VS DECLINATION AND HOUR
     + ANGLE    /)
  107 FORMAT (//21X,I3,22H LIMIT CURVES PLOTTED     )
  113 FORMAT (10X,8F10.4,3I3,4X,A6)
  114 FORMAT (2X,4F10.4,3X,3I3)
  115 FORMAT  (4I5)
  118 FORMAT (12X,2F8.4,20X,I4,2X,A2)
  119 FORMAT (/53X,24HGRID POINTS AT RIGHT END  /8X,5HKET =,7X,I2,10(8X,
     9 I2)/8X,7HELEV.    ,11F10.4/8X,7HAZIM.    ,11F10.4)
 1004 FORMAT ( 1H1 // 45X , 32HENGINEERING SCIENCES LABORATORY /10X,A10,
     C 30X, 23H AEROBALLISTICS BRANCH   //)
C
      DATA DEC/5H23.4N,3H20N   ,3H15N   ,3H10N   ,3H 5N   ,3H0.0   ,3H 5S   ,
     +3H10S   ,3H15S   ,3H20S   ,5H23.4S/
C
      DATA HR/2H4 ,2H5 ,2H6 ,2H7 ,2H8 ,2H9 ,2H10,2H11,2H12,2H13,2H14,
     +2H15,2H16,2H17,2H18,2H19,2H20/
C
      DATA A/984*0.0/
      DATA E/984*0.0/
      DATA AZ/4H   L,4HP    ,4H    T/
      DATA BQ/6HJ CONS,6HK CONS/
C
      DATA D/23.4,20.0,15.0,10.0,5.0,0.0,-5.0,-10.0,-15.0,-20.0,-23.4/
C
      RADN = 57.29578
      CALL DATE (JD)
      CALL PLOT (3.0,5.0,-3)
    1 WRITE (6,1004)  JD
      WRITE (6,105)
C
      READ (5,103) SITE
      READ (5,100) ATU,DLG,RAZ
      IF (EOF(5).NE.0.0) GO TO 311
      READ (5,115) KB
      ATUR = ATU/RADN
      SAT = SIN(ATUR)
```

```
      COT = COS(ATUR)
C
      WRITE (6,103) SITE
      WRITE (6,101) (HR(L),L=1,17,2)
C
      CALL SYMBOL (0.7,6.5,58H  SUN ELEVATION AND AZIMUTH VS DECLINATION
     + AND HOUR ANGLE    ,58,0.21,0.0)
C
      CALL SYMBOL (0.5,6.1,SITE,80,0.17,0.0)
      CALL SYMBOL (1.7,5.6,74HSHOWING LIMIT LINES FOR LAUNCH, PEAK, AND
     +IMPACT AT Q.E. = 30, 45, 60 DEG.   ,74,0.14,0.0)
C
      DO 2 K=1,81
      H = (57.0 + K*3.0) - 180.0
      SNH(K) = SIN(H/RADN)
    2 CSH(K) = COS(H/RADN)
      WRITE (6,104) (SNH(K),K=1,81,10)
C
      CALL AXIS (0.0,0.0,13HAZIMUTH (DEG),13,12.0,0.0,60.0,20.0)
      CALL SYMBOL (0.7,0.4,17HDECLINATION (DEG),17,0.12,  0.0)
      CALL PLOT (0.0,1.0,-3)
      EJS = -0.32
      EJF = -0.1
      JE = 1
      KBT= 1
      KET= 1
C
      DO 517 M=1,81
  517 JQ(M) = 11
C
      DO 59 J = 1,11
C
      DR = D(J)/RADN
      SID = SIN(DR)
      COD = COS(DR)
C
C  SYMMETRY OF GRID USED TO CALCULATE RIGHT SIDE FROM LEFT SIDE.
C
      DO 4 K=1,81
      IF (K.GT.41)  GO TO 57
      SNE = SAT*SID + COT*COD*CSH(K)
      CSE = SQRT(1.0 - SNE*SNE)
      E(J,K) = RADN*  ASIN(SNE)
      E(J,82-K) = E(J,K)
C
      SNA =- COD*SNH(K)/CSE
      CSA = (SID - SNE*SAT)/(CSE*COT)
      A(J,K) = RADN*ATAN2(SNA,CSA)
      IF (A(J,K).LT.0.0)  A(J,K) = A(J,K) + 360.0
      A(J,82-K) = 360.0 - A(J,K)
C
   57 CONTINUE
    4 CONTINUE
   59 CONTINUE
C
```

```
      CALL SCALE (A,984,1,12.0,60.0,20.0,1)
      CALL SCALE (E,984,1, 4.0, 0.0,20.0,1)
       ANB = 0.0
      ANE = 12.0
C
      DO 61 J=1,11
      DO 60 K=1,81
      AA(K)     = A(J,K)
      EE(K)     = E(J,K)
      IF (K.EQ.1) GO TO 60
      IF (K.GT.41) GO TO 55
C
C          J CONSTANT
C
   53 IF (E(J,K+1).LT.0.00.OR.E(J,K).GT.0.00) GO TO 54
      KBT = K + 1
      SLJ = (E(J,KBT) - E(J,KBT-1))/(A(J,KBT)-A(J,KBT-1))
      AJBT = A(J,KBT-1) - E(J,KBT-1)/SLJ
      KET= 82 - KBT
      AJET   = 12.0 - AJBT
C
C          K CONSTANT
C
   54 IF (E(J,K).LT.0.00.OR.E(J+1,K).GT.0.00) GO TO 60
      JE = J
      JG(K) = JE
      JQ(82-K) = JE
      IF (K.GT.KBT.AND.J.EQ.11) GO TO 60
      SLK = (E(JE+1,K) - E(JE,K))/(A(JE+1,K) - A(JE,K))
   51 ANB = A(JE,K) - E(JE,K)/SLK
      ANE = 12.0 - ANB
      KBT = K
      KET = 82 - KBT
      IF (J.EQ.11) GO TO 60
      CALL PLOT (A(J,KBT),E(J,KBT),3)
      CALL PLOT ( ANB,0.0,2)
      IF (J.EQ.11) GO TO 60
      CALL PLOT (A(J,KET),E(J,KET),3)
      CALL PLOT  (ANE,0.0,2)
   55 CONTINUE
   60 CONTINUE
C
      NK = KET- KBT+ 1
C
      IF(EE(KBT).LT.0.001) GO TO 62
      CALL PLOT (AA(KBT)   ,EE(KBT),3)
      CALL PLOT (AJBT    ,0.0,2)
C
C                  WRITE DECLINATIONS
C
   62 CONTINUE
C
    6 IF (J.EQ.1) GO TO 3
      IF (MOD(J,2).NE.0) GO TO 58
      AJS = AJBT - 0.17
```

```
      CALL SYMBOL (AJS,EJS,DEC(J),3,0.12, 53.0)
      IF (J.EQ.4.OR.J.EQ.6.OR.J.EQ.8) GO TO  3
      GO TO 58
    3 XJ = AA(41) - 0.18
      YJ = EE(41) - .06
      CALL SYMBOL (XJ,YJ,DEC(J),5,0.12,0.0)
   58 CONTINUE
       IF (J.NE.11) GO TO 64
      SJX = AJBT - 0.28
      SJY = - 0.49
      CALL SYMBOL (SJX,SJY,DEC(J),5,0.12, 53.0)
C
   64 CALL LINE (AA(KBT),EE(KBT),NK,1,0,0,0)
C
      IF(EE(KET).LT.0.001) GO TO 63
      CALL PLOT (AA(KET),EE(KET),3)
      CALL PLOT (AJET       ,0.0,2)
C
   63 CONTINUE
      KB(JE) = KBT
      KE(JE) = KET
      IF (J.EQ.1) GO TO 5
      IF (MOD(J,2).NE.0) GO TO 5
      AJF = AJET
      CALL SYMBOL (AJF,EJF,DEC(J),5,0.12,-53.0)
C
    5 CONTINUE
      IF (J.NE.11) GO TO 61
      SJX = AJET
      CALL SYMBOL (SJX,EJF,DEC(J),5,0.12,-53.0)
C
   61 CONTINUE
C
      L = 1
C
      KBT = KB(1)
      KET = KE(1)
C
      DO 9 K=KBT,KET
      CALL LINE (A(1,K),E(1,K),JQ(K   ),1,0,0,0)
      IF (K.EQ.1) GO TO  10
      M = K - 1
      IF (MOD( M,5).NE.0)  GO TO 9
   10 CONTINUE
C
C               WRITE HOUR ANGLES
C
      IF ( K.NE.41) GO  TO 15
      XU = A(1,41)
      YU = E(1,41) + .1
      XL = A(11,41)
      YL = E(11,41) - .1
      ABU = XU - .08
      EBU = YU + .03
      ABL = XL - .08
```

```
      EBL = YL - .13
      GO TO 17
C
   15 SLPU = (E(2,K) - E(1,K))/(A(2,K) - A(1,K))
      SLPL = (E(11,K) - E(10,K))/(A(11,K) - A(10,K))
      IF (SLPL.EQ.0.0) GO TO 9
      XL =  A(11,K) - .1/SLPL
      YL =  E(11,K) - .1
C
       IF ( K.GT.41) GO TO 13
      IF (SLPU.EQ.0.0)  GO TO 9
      XU = A(1,K) - .1
      YU = E(1,K) - .1*SLPU
      ABU = XU  - .08
      EBU =YU + .02
C
      IF (K.NE.31) GO TO 14
      AHA = ABU - 0.9
      EHA = EBU - 0.6
      CALL SYMBOL ( AHA, EHA,17HLOCAL HOUR ANGLES,17,0.12,45.0)
   14 ABL  = XL
      EBL = YL - .12
       GO TO 17
C
   13 IF (SLPU.EQ.0.0)  GO TO 9
      XU = A(1,K) + .1
      YU = E(1,K) + .1*SLPU
      ABU = XU - 0.07
      EBU = YU + 0.02
      ABL = XL - .10
      EBL = YL - .13
C
   17 CONTINUE
C
      L = 1 + K/5
      CALL SYMBOL ( ABU,EBU,HR(L),2,0.12,0.0)
      CALL PLOT (XU,YU,3)
      CALL PLOT (A(1,K),E(1,K),2)
      IF (K.LT.KB(11)) GO TO 9
      IF (K.GT.KE(11))  GO TO 9
      CALL PLOT (A(11,K),E(11,K),3)
      CALL PLOT (XL,YL,2)
      CALL SYMBOL ( ABL,EBL,HR(L),2,0.12,0.0)
    9 CONTINUE
   42 CONTINUE
C
      CALL AXIS(12.0,0.0,15HELEVATION (DEG),-15,4.0,90.0,  0.0,20.0)
      CALL AXIS (0.0,0.0,15HELEVATION (DEG), 15,4.0,90.0,  0.0,20.0)
C
      IF (KR.EQ.0)  GO TO 311
C             LIMIT CURVES PLOTTED.  IF  KR.GT.ZERO
C
      IR = 0
   19 M = 1
   20 READ (5,118) AS(M),ES(M),ITEMP,MQP
```

```
      IF (EOF(5).NE.0.0)GO TO 21
      I = ITEMP
      MOE = MOP
      M = M +1
      GO TO 20
C
   21 J = M - 1
      CALL SCALE (AS,J,1,12.0,60.0,20.0,1)
      CALL SCALE (ES,J,1, 4.0, 0.0,20.0,1)
      CALL LINE  (AS,ES,J,1,0,0,0)
C
      WX = AS(J) + .05
      WY = ES (J)
C
      IF  (I.EQ.2)  GO TO 24
C
      CALL SYMBOL (WX,WY,MOE,2,0.12,0.0)
   22 CALL SYMBOL  (WX,WY,AZ(I)  ,4,0.12,0.0)
       GO  TO 28
C
   24 CALL SYMBOL (WX,WY,AZ(I), 4,0.12,0.0)
C
   28 IR = IR + 1
      IF (IR.LT.NR)  GO TO 19
      CALL SYMBOL (5.43,0.30,10HL = LAUNCH,10,0.12,0.0)
      CALL SYMBOL (5.586,0.05, 8HP = PEAK,  8,0.12,0.0)
      CALL SYMBOL (5.4  ,-.20,12HT = TERMINAL,12,0.12,0.0)
      WRITE (6,107)  IR
C
  311 STOP
      END
```

```
      PROGRAM YSYEAR(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT)
C
C         PROGRAM PLOTS YAW SONDE WINDOWS FOR WHOLE YEAR
C
      DIMENSION DYN(50),CVT(50),HR(14),QE(3),EMP(22),DUN(22)
     +,MON(22),SITE(8),NSY(6)
C
C        CHINA LAKE CURVES.
C
  101 FORMAT (4I5)
  102 FORMAT (12F6.0)
  103 FORMAT (8A10)
  104 FORMAT  ( // 17X,I3,15H CURVES PLOTTED)
  118 FORMAT ( A6,F6.0,4F8.4,4I.)
  119 FORMAT (//43X,36H YEAR CHART OF YAW SONDE WINDOWS AT  /)
  120 FORMAT (2(10X,4HDATE,11(4X,A6)/10X,4H CVT,11(F10.2)/)/)
 1004 FORMAT ( 1H1 // 45X , 32HENGINEERING SCIENCES LABORATORY /10X,A10,
     C 30X, 23H AEROBALLISTICS BRANCH  )
C
      DATA HR/2H 6,2H 7,2H 8,2H 9,2H10,2H11,2H12,2H13,2H14,2H15,2H16,
     +2H17,2H18,2H19/
C
      DATA EMP/0.0667,0.1833,0.2333,0.2167,0.1833,0.1167,0.0667,0.0,
     A-0.05,-0.0667,0.0333,0.10,0.0833,0.0333,-0.05,-0.1333,-0.20,
     B-0.25,-0.2667,-0.2333,-0.0333,0.0333/
C
      DATA DUN/ 1.0,
     +           21.0,39.0,54.0,68.0,81.0,93.0,107.0,122.0,141.0,173.0,
     C 205.0,225.0,240.0,254.0,267.0,280.0,293.0,308.0,326.0,356.0,
     D   366.0/
C
      DATA MON/6HJAN  1,6HJAN 21,6HFEB  8,6HFEB 23,6HMAR  8,6HMAR 21,
     A 6HAPR  2,6HAPR 16,6HMAY  1,6HMAY 20,6HJUN 21,6HJUL 23,6HAUG 12,
     B 6HAUG 27,6HSEP 10,6HSEP 23,6HOCT  6,6HOCT 19,6HNOV  3,6HNOV 21,
     C 6HDEC 21,6HDEC 31/
C
      DATA NSY/03,04,06,00,62,51/
C
      CALL DATE(JD)
       CALL PLOT (0.0,0.0,-3)
      CALL SYMBOL (0.0,7.2,JD,10,0.14,0.0)
      CALL SYMBOL(2.5,7.2,35HYAW SONDE WINDOWS FOR WHOLE YEAR   ,35,0.18
     +,0.0)
    7 READ (5,103) SITE
      IF (EOF(5).NE.0.0) GO TO 49
      READ (5,102) ATU,DLG,RAZ
      CALL SYMBOL (0.3,5.7, SITE,80,0.14,0.0)
C
C             LQ  1      MQ  30
C             LQ  2      MQ  45
C             LQ  3      MQ  60
C             LQ  4      PEAK
C             LQ  5      SUNSET
C             LQ  6      SUNRISE
C
```

```
C         KTG = 1 FOR POSITIVE SLOPE (LAUNCH)
C         KTG = 2 FOR NEGATIVE SLOPE (IMPACT)
C         KTG = 3 FOR SUNSET LINE
C
C         NST = 0 FOR STANDARD DATES (22 OF THEM)
C         NST = 1 FOR INTERMEDIATE DATES
C        NCRV = NUMBER OF CURVES TO BE DRAWN
C
      READ (5,101) NCRV
      WRITE (6,1004) JD
      WRITE (6,119)
      WRITE (6,103)     SITE
      NC = 0
    9 I = 1
   11 READ (5,118) AED,DYN(I),BAS,BES,SHA,BMP,LIP,KTP,MQP,NSP
      IF (EOF(5).NE.0.0) GO TO 12
      LQ  = LIP
      KTG = KTP
      MQ = MQP
      NST = NSP
      IF (NST.EQ.1) GO TO 21
      CVT(I) = SHA - FMP(I) + DLG
      DYN(I) = DUN(I)
      GO TO 22
   21 CVT(I) = SHA - BMP + DLG
   22 I = I + 1
      GO TO 11
C
   12 N = I - 1
      CALL SCALE (DYN,N,1,10.0,0.0,36.6,1)
      CALL SCALE (CVT,N,1,7.0, 6.0,1.818,1)
      CALL LINE (DYN,CVT,N,1,NSY(LQ),0.10,0)
C
      IF (LQ.EQ.6) GO TO 40
      IF (KTG.NE.3)  GO TO 41
C
      CALL SYMBOL (8.70,6.35,6HSUNSET,6,0.10,-16.0)
      GO TO 41
   40 CALL SYMBOL (8.30,0.57,7HSUNRISE,7,0.10,17.0) .
C
   41 NC = NC + 1
      IF (NC.LT.NCRV)  GO TO 9
C
C             DRAW HOUR LINES
      DO 45 K=1,13
      YH = 0.55 * (K - 1)
      YL = YH + .02
      YR = YH - .07
      CALL SYMBOL (0.05,YL,HR(K),2,0.12,0.0)
      CALL PLOT (0.0,YH,3)
      CALL PLOT (10.0,YH,2)
      CALL SYMBOL(10.04,YR,HR(K),2,0.12,0.0)
   45 CONTINUE
C
C             DRAW VERTICAL AXES
```

```
C
      CALL PLOT (10.0,6.85,3)
      CALL PLOT(10.0,0.0,2)
      CALL SYMBOL (-0.05,2.5,19HCIVIL STANDARD TIME,19,0.12,90.0)
      CALL PLOT ( 0.0,6.85,3)
      CALL PLOT (0.0,0.0,2)
C
      CALL SYMBOL (3.8,5.2,20HALL SEGMENTS VISIBLE,20,0.14,0.0)
      CALL SYMBOL (3.8,0.6,20HALL SEGMENTS VISIBLE,20,0.14,0.0)
      CALL SYMBOL ( 7.1,2.9,22H30T AND PEAK INVISIBLE,22,0.14,0.0)
      CALL SYMBOL ( 0.7,3.0,22HPEAK AND 30T INVISIBLE,22,0.14,0.0)
      CALL SYMBOL (3.95,3.5,13H60L INVISIBLE,13,0.14,0.0)
      CALL SYMBOL (3.5,1.8,17HIMPACTS INVISIBLE,17,0.14,0.0)
C
      CALL SYMBOL (9.20,3.90 , 7HSYM  QE,7,0.10,0.0)
      CALL SYMBOL (9.20,3.715, 7H 0    0,7,0.10,0.0)
      CALL SYMBOL (9.20,3.577, 7H 3   30,7,0.10,0.0)
      CALL SYMBOL (9.20,3.439, 7H 4   45,7,0.10,0.0)
      CALL SYMBOL (9.20,3.301, 7H 6   60,7,0.10,0.0)
      WRITE (6,104)   NC
   49  STOP
      END
```